Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories

Laboratoires de recherche minière

Canada

C:\PROJ\$CO_2$CTL90.01

AN EXAMPLE OF AIR QUALITY CONTROL IN DIESELIZED MINE WORKINGS BY MONITORING OF AMBIENT CO_2

E. Don Dainty

CANADIAN EXPLOSIVE ATMOSPHERES LABORATORY

MRL 90-14 (TR)

March 1990

MICROMEDIA

This document is an unedited interim report prepared primarily for discussion and internal reporting purposes. It does not represent a final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire non révisé préparé principalement pour discussion et diffusion au sein de [illegible] Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

10 pp

90-06007/

AN EXAMPLE OF AIR QUALITY CONTROL IN DIESELIZED MINE WORKINGS BY MONITORING AMBIENT CO_2

by E. Don Dainty *

SUMMARY

These calculations demonstrate that it is possible to control, by monitoring CO_2 levels in mines, occurrences of excessive exposure of underground workers (particularly vehicle operators) to toxic air-borne contaminants.

In the case of this assumed example, two heavily-loaded LHD machines (powered by Deutz F6L 714 engines with no after-treatment devices installed), are operating in the same ventilation stream which is provided with clean fresh air from the intake (the CO_2 of fresh air is 350 ppm). The control CO_2 concentration (that for maximum permissible exposure equivalent to an AQI of 3.0) is calculated to be 1667 ppm.

A catalytic purifier would not affect these values significantly.

If a ceramic filter were applied, and the maximum ventilation reduction implemented, then the control CO_2 value increases to 2971 ppm for an AQI = 3. If only 50% of the possible ventilation reduction is implemented, then the control CO_2 becomes 2319 ppm.

Were ventilation control to be implemented (assuming 100% ventilation reduction benefit due to filter application), the monitored value of the CO_2 at the outlet from the area of concern (or the exposure of the second vehicle operator), would be defined by the following equation:

$$CO_2 \text{ at exit} = \frac{\text{AQI @ exit} - 0.316}{0.009035} \%$$

Installation of ceramic filters in the place of no exhaust treatment or catalytic purifiers, would permit an additional 2 production LHD machines in the same work area while maintaining an AQI = 3. If 50% of the pollution reduction due to the filter were attributed to the environment, then only one additional machine would be acceptable.

---

* Research Scientist, Canadian Explosive Atmospheres Laboratory, Mining Research Laboratories, CANMET/EMR

EXEMPLE DE CONTROLE DE LA QUALITE DE L'AIR DANS UNE MINE AVEC EQUIPEMENT DIESEL PAR SURVEILLANCE DU CO_2 AMBIANT

par E. Don Dainty*

RESUME

Ces calculs montrent qu'il est possible de gérer, par surveillance du CO_2 dans les mines, les expositions excessives des travailleurs souterrains (en particulier les opérateurs de véhicules) aux contaminants atmosphériques toxiques.

Dans le cas de cet exemple hypothétique, deux chargeuses-transporteuses fortement chargées (mues par des moteurs Deutz F6L 714 non munis de dispositifs post-traitement) fonctionnent dans le même circuit de ventilation qui est alimenté en air frais propre à partir de la prise (l'air frais contient 350 ppm de CO_2). La concentration témoin de CO_2 (qui pour une exposition admissible maximale équivaut à un IQA de 3,0) est évaluée à 1667 ppm.

La pose d'un purificateur catalytique ne modifierait pas sensiblement ces valeurs.

Si un filtre en céramique était installé et que la ventilation était réduite au maximum, la concentration témoins de CO_2 grimperait à 2971 ppm pour un IQA = 3. Si la ventilation était réduite de moitié. la concentration témoins serait de 2319.

Si des mesures de réduction de la ventilation devaient être introduites (en supposant que la ventilation est réduite de 100 % lorsqu'un filtre est installé), la concentration de CO_2 contrôlée à la sortie de la zone d'intérêt (ou l'exposition de l'opérateur du deuxième véhicule) serait définie par l'équation suivante:

$$CO_2 \text{ à la sortie} = \frac{\text{IQA à la sortie} - 0{,}316}{0{,}009035} \ \%$$

Si on installait des filtres en céramique au lieu de ne pas traiter les gaz d'échappement ou de s'en tenir à des purificateurs catalytiques, on pourrait ajouter 2 véhicules de production dans la même aire de travail tout en maintenant un IQA - 3. Si la réduction de moitié de la pollution grâce au filtre était attribuable à l'environnement, l'ajout d'une seule machine serait acceptable.

---

*Chercheur scientifique, Laboratoire canadien des atmosphères explosives, Laboratoires de recherche minière, CANMET/EMR.

AN EXAMPLE OF AIR QUALITY CONTROL IN DIESELIZED MINE WORKINGS BY MONITORING AMBIENT CO_2

INTRODUCTION

A number of mine operators have expressed interest in monitoring of the mine environment for toxic diesel emissions, and in the possible advantages that can be gained from so doing. One such advantage could be the assurance of ventilation adequacy for underground workers by the monitoring of CO_2 concentrations as a surrogate for all the major pollutants. The relationships of the CO_2 concentrations involved to the toxicity of the underground environment, and therefore the adequacy of the ventilation supplied, are explored in this simplified theoretical example.

A further step in this process would be the control of ventilation using the signals monitored when the available ventilation proves insufficient according to the toxicity criterion in force.

DESCRIPTION OF THE OPERATION

It is assumed that two LHD production machines are operating on a single level in two areas served by the same ventilation circuit as shown in Fig. 1. The LHDs are each powered by a Deutz F6L 714 engine having operating characteristics and emissions as given in Table 1.

LHDs in this type of simple cycle would likely be heavily loaded near to full load/speed conditions. For this study it is assumed that both machines operate at full load/speed.

The ventilation available for both machines is 42,385 cfm; enough to result in an AQI equal to the limit of three for the downstream station D. The drift cross-sectional area is 16 ft wide by 12 ft high (192 sqft), so that the velocity of the ventilation through the drift is 221 fpm or 3.68 fps.

It is assumed that the first machine is operating in such a way that ventilation leaving its area is fully mixed, so that the ventilation entering the area where the second machine is operating has a constant analysis of toxic constituents.

With this set of circumstances, it is possible to calculate the ventilation-related parameters, as demonstrated in the following sections.

Table 1 - Deutz F6L 714 Engine Operating and Emissions Parameters

item	units	value
engine load	%	100
engine speed	%	100
power	bhp	133
speed	rpm	2200
torque	lb.ft	318
fuel/air ratio	-	0.046
dry air flow	lb/hr	1,320
	cfm	293
fuel rate	lb/hr	60.7
water production	lb/hr	77.0
wet gas flow	lb/hr	1,381
dry exhaust gas	lb/hr	1,304
	cfm	280
CO_2 concentration	%	10.0
CO	ppm	147
NO	ppm	552
NO_2	ppm	10
SO_2	ppm	87.2
soot	mg/m^3	59.5
EQI	-	219.4
ventilation (AQI = 3)	scfm	21,192

CALCULATIONS OF VENTILATION-RELATED PARAMETERS

Ventilation Requirement (see Table 1 and CSA M424.2)

$$\text{dry ventilating air } (Q_{dva}) = \frac{\text{dry exhaust gas flow (lb/hr) X EQI/3}}{\text{60 X ventilating air density (lb/ft3)}} \text{ cfm}$$

$$= \frac{1304 \text{ X } 219.4/3.0}{60 \text{ X } 0.075} = \textbf{21,192 cfm/machine}$$

For two machines operating at full load, this dry ventilating air per machine would have to be doubled to **42,385 cfm**.

Average CO_2 Concentrations

The average integrated CO_2 concentrations leaving the area where each machine is operating can be determined from a volume rate flow balance of the total flow leaving the area (Q_{total}) which equals the

dry ventilating air (Q_{dva}) supplied, less the dry combustion air (Q_{dca}) flow, plus the dry exhaust gas (Q_{dxg}) generated by combustion in the engine - as follows for station A:

$$Q_{total} \times CO_{2total} = (Q_{dva} - Q_{dca}) \times CO_{2dva} + Q_{dxg} \times CO_{2dxg}$$

and therefore, using the calculated ventilation and data from Tables 1 and 2:

$$CO2 @ A = \frac{(42{,}385 - 293) \times 350 + 280 \times 100{,}000}{(42{,}385 - 293) + 280} = \mathbf{1008.4\ ppm},\ \&$$

$$CO2 @ D = \frac{(42{,}385 - 2X293) \times 350 + 2X280 \times 100{,}000}{41{,}799 + 560} = \mathbf{1667.4\ ppm}$$

Corresponding Pollutant Concentrations

The dilution ratio is defined from the ventilation equation as EQI/3, which in this case is 219.4/3 = **73.1**. This ratio is used to calculate the pollutant concentrations as given in the Table 2.

Table 2 - CO_2, AQI and Pollutant Concentrations

station	CO_2 (ppm)	CO (ppm)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)	soot (mg/m^3)	EQI engine	EQI filter
engine	100,000	147	552	10	87.2	59.5	219.4	-
fresh air	350	-	-	-	-	-	0.00	0.00
A	1008	1.00	3.77	0.07	0.59	0.407	1.50	0.60
D	1663	2.01	7.55	0.14	1.19	0.814	3.00	1.19

The values for the filter in Table 2 are produced by assuming a soot removal efficiency of 90% and using all the other values. For example:

$$AQIfilter = \frac{CO}{50} + \frac{NO}{25} + \frac{soot}{1.5} + 1.5\left[\frac{SO2}{3.0} + \frac{soot}{1.5}\right] + 1.2\left[\frac{NO2}{3.0} + \frac{soot}{1.5}\right]$$

$$= \frac{2.01}{50} + \frac{7.55}{25} + \frac{0.0814}{1.5} + 1.5\left[\frac{1.19}{3.0} + \frac{0.0814}{1.5}\right]$$

$$+ 1.2\left[\frac{0.14}{3.0} + \frac{0.0814}{1.5}\right] = \mathbf{1.19}$$

CO_2 Control for an AQI = 3

From the data in Table 2, the relationship of CO_2 and AQI are seen to be linear for the bare engine. These are plotted in Fig. 2. To calculate the control CO_2 for the filter corresponding to an AQI = 3, the equation of the lines must be determined as follows:

$$\text{AQI} = \text{slope} \times CO_2 - \text{intercept on AQI axis}$$

$$\text{therefore, AQI filter} = \frac{\text{AQI change}}{CO_2 \text{ change}} \times CO_2 \text{ filter} - \text{intercept}$$

when AQI = 0, CO_2 is 350 ppm for fresh air, and

$$0 = \frac{1.19 - 0}{1667 - 350} \times 350 - \text{intercept}$$

therefore, 0.0009035 X 350 = intercept = 0.316, and therefore

$$\underset{(100\%)}{\text{control } CO_2 \text{ filter}} = \frac{\text{AQI filter} - \text{intercept}}{0.0009035} = \frac{3.0 - 0.316}{0.0009035}$$

= **2971 ppm** as given in Table 2

Therefore, if the two machines are fitted with filters, and 100% of the filter action is accorded to a reduction in ventilation maintaining the AQI at 3, then the control CO_2 at station D would be 2960 ppm. If 50% of the credit due to filter action is accorded to ventilation reduction, then the control CO_2 level would be:

$$\underset{(50\%)}{\text{control } CO_2 \text{ filter}} = 1667 + 0.5(2971 - 1667)$$

= **2319 ppm**

When the appropriate control CO_2 limit is reached for a machine with no exhaust treatment, several things could happen: (1) a light, triggered by a machine-mounted CO_2 sensor signal could illuminate on the machine control panel to indicate excess operator exposure, (2) production could be reduced by reducing the number of operating machines, (3) ventilation to the area could be increased by an automated ventilation control system, or (4) filters or other effective control devices could be installed to reestablish ventilation adequacy.

The control CO_2 value of 2971 ppm for the filtered engine exhaust option, suggests that additional machines could be placed in the work area. This is calculated in the following section.

Relationship of Power to Ventilation and CO_2 Concentration

The following equation is derived from first principles:

$$\text{operating HP} = \frac{\text{ventilation (cfm) X (net \% } CO_2)}{\text{46.1 X brake specific fuel consumption}}$$

This equation is a check on the above calculations, as follows:

$$\text{operating HP} = \frac{42{,}385 \text{ X } (0.1667 - 0.0350)}{46.1 \text{ X } 0.456} = \mathbf{266 \text{ hp}}$$

compared to 2 X 133 = 266 hp actually.

For the filtration option, the operating hp permitted, assuming an AQI = 3.0, is:

$$\text{permissible hp} = \frac{42{,}385 \text{ X } (0.2971 - 0.0350)}{46.1 \text{ X } 0.456} = \mathbf{528 \text{ hp}}$$

This would allow 4 machines (528/133 = 4) to operate in these circumstances. Were the 50% benefit rule applied, a total of 3 machines would be permissible.

This equation also provides an overall load factor or utilization efficiency of the installed diesel power in the mine, as follows:

$$\text{load factor} = \frac{\text{operating hp}}{\text{installed hp}} = \frac{266}{2 \text{ X } 133} = \mathbf{1.00} \text{ as assumed}$$

MONITORING CONSIDERATIONS

Underground environment monitoring could be implemented to ensure that adequate ventilation on a level is provided. In that case, the following items must be known:

(1) the total installed hp of the vehicles in the area of concern,

(2) the emissions characteristics of the engines installed in the vehicles. Deutz FnL 714, FnL 413 and FnL 912W series engines have similar emissions characteristics which are also similar to other IDI engine varieties,

(3) the ventilation to the work area of concern,

(4) the CO_2 in the air entering the area, and

(5) the CO_2 in the air leaving the area of concern.

The brake specific fuel consumption BSFC for IDI engines is relatively constant at 0.45 +/- 0.05 lbs/(bhp.hr).

Knowledge of these parameters allows the establishment of the equation for adequate ventilation based on CO_2. In this example, for the operator, or for station D, it takes the form of:

$$CO_2 = \frac{AQI\ @\ D - 0.316}{0.009035}\ ppm$$

For a resume of the above considerations, refer to the summary at the beginning of this study.

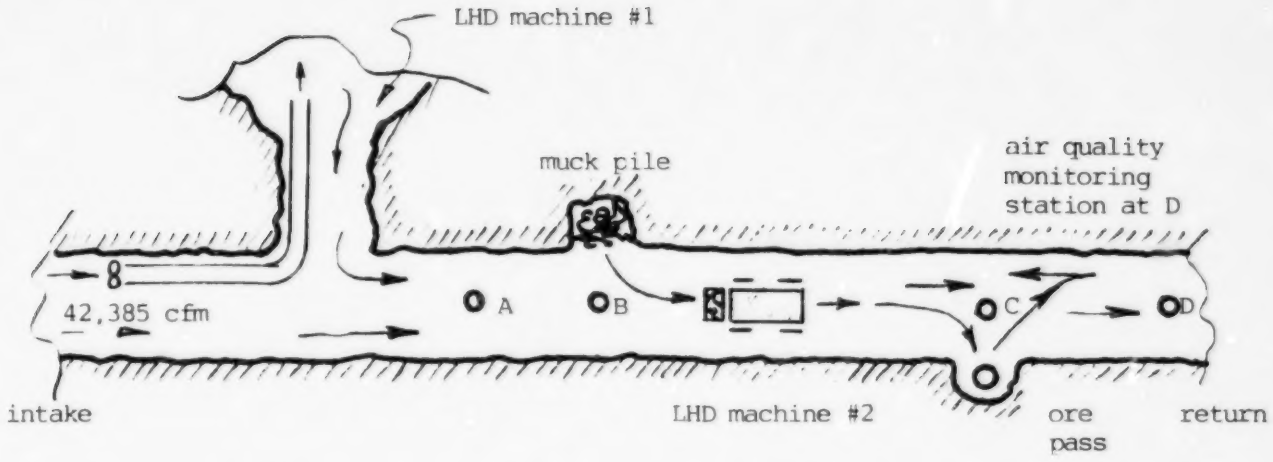

Fig. 1 - Plan Layout of Operating Level

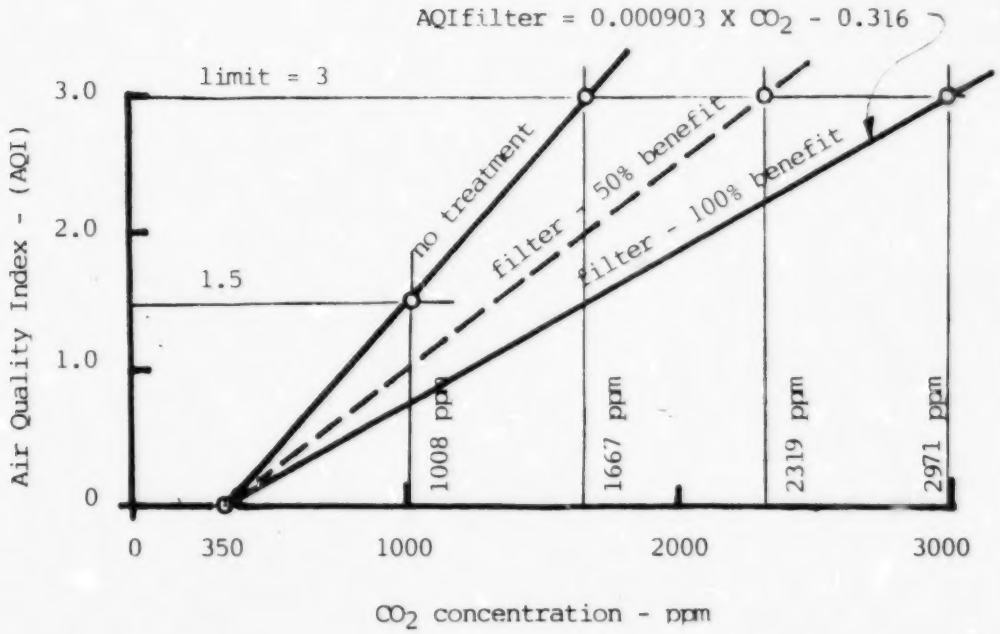

Fig. 2- AQI vs CO_2 Concentration
on LHD or at Station D